Chapter 7

General discussion
7. GENERAL DISCUSSION

The main objective of this thesis was to determine the biomechanical mechanisms through which power training improves old adults’ walking speed. A literature review identified a gap in our knowledge as to the actual mechanisms through which interventions in general and, in particular, strength and power training improve walking speed in old age (chapter 2). This review advocated that, to increase the efficacy of exercise training designed to improve locomotor function in old adults, there is a need to study the biomechanical mechanisms that underlie training-induced gains in gait velocity. The Potsdam Gait Study (POGS) was designed to address this issue through examining the effects of lower extremity power training on old adults’ gait biomechanics (chapter 3). Fig. 7.1 provides an overview of the main findings of POGS, showing an increase in lower-extremity muscle strength and power, along with improved fast gait velocity and adaptations in joint kinematics, joint kinetics, and muscle activation (chapters 4-6). The training-induced changes in physical capacity did not correlate with changes in gait biomechanics (chapters 4 and 5). Next, the main findings of this thesis are discussed in more detail.

7.1. POWER TRAINING TO IMPROVE MUSCLE FUNCTION IN THE ELDERLY

In this thesis, lower-extremity power training in healthy old adults resulted in increased muscle strength and power (chapter 4 to 6). These findings add to the body of literature that recommends the use of progressive resistance training with a strengthening and velocity component to counter age-related muscle weakness and improve muscle function [1–4]. Despite that power training (i.e., moderate heavy weights and with high movement velocities) compared with strength training (i.e., heavy weights and slow movement velocities) is a more effective training method for enhancing muscle power and functional performance in old age, the optimal dose-response relationship regarding specific power training components (i.e., training load, volume, frequency, or duration) are yet to be determined [3,5,6].

Figure 7.1. Summary of the results of the Potsdam Gait Study (POGS), as described in chapter 4 to 6. The figure shows the effects of 10 weeks of lower extremity power training on gait mechanics during fast walking in healthy old adults.
Previous research showed that resistance training evokes adaptations in old adults’ muscles morphology, such as an increase in the number and size of muscle fibers (i.e., muscle hypertrophy) or an increase in proportion of type II muscle fibers, which contributes to gains in muscle strength and power [7,8]. It is unclear if the present power training caused such favorable adaptations because no measurements of muscle morphology were taken. However, there is strong evidence that that training-induced increases in muscle strength or power after a relatively short period (i.e., 6-9 weeks) are generally neuromuscular in nature [9–13]. This thesis supports this idea and shows that power training-induced increases in muscle strength correlated with increases in neuromuscular activation, which appeared in an increase in the magnitude of surface electromyography (EMG) amplitude of the agonist muscle (chapter 6). Mechanisms underlying the power training-induced increase in neural drive may include increased motor neuron and/or muscle fiber excitability, increased number of active motor neurons, and/or increased conduction velocity [8,14]. Additionally, chapter 6 shows that antagonist coactivation was unchanged after power training, providing evidence that the training-induced increases in muscle strength was the result of increased force production of the agonist muscles rather than a decrease in force production of the counteracting antagonist muscles. Notably, antagonist coactivation is important for joint stabilization, which is one possible explanation why antagonist coactivation was unchanged after power training [12]. Overall, because training-induced gains in strength and power are initially neural in nature, a better understanding of power training-induced adaptations in the neuromuscular pathway is needed to optimize exercise interventions that aim to counter age-related loss of muscle strength and power.

7.2. INCORPORATION OF TRAINING-INDUCED GAINS IN MUSCLE POWER INTO GAIT
The review in this thesis shows that exercise-induced gains in lower extremity power are usually of greater magnitude than gains in walking speed (chapter 2), indicating only minimal incorporation of the newly acquired power ability into gait. The results of POGS confirm these findings as gains in training loads and muscle power were generally greater than, and not associated with, gains in walking speed (chapters 4 and 5). One way to explain these findings is perhaps via the concept of relative effort. Chapter 2 discussed that biomechanical plasticity of gait predicts little incorporation of newly acquired abilities into gait when the relative effort is low in this joint. This thesis provides evidence for this concept with regards to knee extensor function. The old adults already operated at low knee extensor effort during gait relative to the maximal knee extensor capacity (i.e., 20-45%, chapter 5) before power training, and although knee extensor capacity improved by ~25% via power training (chapters 4 and 5), mechanical output around the knee joint was unchanged (chapter 5). Despite no incorporation of the newly acquired knee extensor abilities into gait, the old adults presumably benefited from the
power training because the improved maximal knee extensor ability resulted in a reserve capacity that could be used to e.g. avoid a fall after a trip. Overall, the results of this thesis suggest that knee extensor capacity is not a limiting factor for walking in healthy elderly because the relative effort during gait is already low.

Chapter 2 provided indirect evidence that the relative effort at the ankle joint during gait is high, which presumably causes ineffective push-off, short steps, and slow walking speed in the elderly. The results of POGS confirm that the relative effort at the ankle joint during gait is high (chapter 5). Indeed, the relative effort of the plantarflexors during gait was 7 to 10 times larger than the maximal capacity measured during isokinetic testing (chapter 5). The above maximal capacity values are the results of the isokinetic testing protocol that underestimated the maximal plantarflexor power capacity. One factor that possibly limited the maximal power estimation during isokinetic testing is the speed at which the test was performed. Indeed, the classic force-velocity curve predicts that power production is maximal at one-third of maximal muscle force or at one-third of maximal contraction velocity [15]. However, POGS measured isokinetic plantarflexor power at maximal 60°/s, which was at only one-fifth of the maximal plantarflexor velocity measured during gait (274°/s, chapter 4). In addition, the methods for calculating muscle power are different between isokinetic and gait testing, i.e., direct versus inverse dynamics. Another factor that possibly contributed to the underestimation of plantarflexor capacity during isokinetic testing is the minimal influence of elastic structures. Early studies showed that energy is stored in the active muscle-tendon unit during stretch in early stance, which is recovered during subsequent shortening phase during push-off [16,17]. Due to the large discrepancy between the nature and procedure between isokinetic power and gait testing, the effects of power training on relative plantarflexor effort during gait remains to be determined. Perhaps a better estimate of maximal plantarflexor power capacity can be determined by using inverse dynamics calculations during a high velocity movement that involved great plantarflexor effort, such as a countermovement jump or a hopping task [18].

An alternative explanation for the lack of incorporation of newly acquired knee extensor and plantarflexor power into gait is the absence of an enabling mechanism that allows the use of the extra capacity during walking. That is, perhaps the old adults need to learn or train how to utilize the new abilities during gait. For example, there is evidence that healthy old adults can improve plantarflexor work during gait when provided real-time feedback about their push-off force [19]. Notably, the old adults in that study [19] did not improve maximal plantarflexor capacity, yet the elderly learned how to better utilize their available capacity. One way to increase the use of power training-induced increases in muscle function during gait is by supplementing it with specific gait training.

The old adults in the current thesis increased hip extensor output during gait after power training (chapter 5). However, it remains unclear if the old adults incorporated newly acquired hip extensor capacity after power training into gait,
because maximal hip capacity was not measured. It is likely that the old adults increased the hip mechanical output after power training to a level that was already available before the intervention but for some reason was unused. Chapter 2 shows that the relative effort of the hip extensors during gait is \(~30\%\), which provides indirect evidence for such findings. Overall, this thesis shows that power training-induced improvements in knee and ankle muscle power did not transfer into gait, while power training resulted in increased mechanical output around the hip joint.

This thesis, for the first time, shows that removal of the exercise stimulus further increased fast gait velocity and evoked reciprocal adaptations in joint kinematics and kinetics in healthy old adults (chapters 4 and 5). At the same time, there was no change in muscle strength or power and these results add to the previous described observation that there is no direct link between gains in muscle strength or power and locomotor performance. It is possible that the increased levels of lower extremity power after completing the power-training program caused alterations in the elderly’s daily activity patterns, which contributed to maintenance of the levels of lower extremity. At the same time, an increase in activity pattern provided the required stimulus that enables the elderly to exploit the newly acquired abilities more effectively.

7.3. BIOMECHANICAL MECHANISMS UNDERLYING IMPROVEMENTS IN GAIT VELOCITY

In the present thesis, power training improved fast gait velocity and chapters 4 to 6 identified various adaptations in gait biomechanics and neuromuscular activation that correlated with increases in old adults’ gait velocity. Because gait velocity is the product of stride length and cadence \([20,21]\), adaptations in one or both of these variables will affect walking speed. This thesis provides evidence that the old adults walked faster after power training by using the strategy of higher cadence rather than increased stride length (chapter 4). Additionally, the old adults increased the mechanical output around the hip joint after power training (chapter 5). Elderly compared with young gait is generally characterized by both higher cadence and increased hip mechanical output \([22–25]\) and this thesis shows that elderly further rely on these functions to improve gait velocity after lower extremity power training. While, biomechanical plasticity of gait predicts that elderly increase proximal hip muscle function to compensate for reductions in plantarflexor capacity, however, this thesis shows that large improvements in plantarflexor capacity did not counteracted the distal-to-proximal shift in muscle function. These results add to previous findings that the age-related distal-to-proximal shift in muscle function during gait in the elderly is robust, because it was present in even fit and healthy elderly \([26–28]\).

In addition to gait mechanics, this thesis for the first time determined the effects of power training on neuromuscular activation during gait in old adults. Training-induced gains in plantarflexors activation during late stance correlated with gains in fast gait
velocity (chapter 6). The role of improved neuromuscular activation of the plantarflexor muscles during gait is yet to be determined, because plantarflexor mechanical output was unchanged (chapter 5). Notably, the plantarflexor mechanical output measured during gait using inverse dynamics is the net summation of all muscle activity surrounding the joint [29]. It is possible that power training also increases neuromuscular activation of the antagonist muscles (i.e., dorsiflexors) that produces counteracting force. There is a need for a more detailed examination of the association between power training-induced changes in gait mechanics and neuromuscular outcomes.

7.4. LIMITATIONS AND RECOMMENDATIONS
This thesis has several limitations. First, as discussed before, it is recommended for future studies to relate measurements of maximal hip muscle capacity to the mechanical output produced during gait. This, together with measurements of neuromuscular activation of the hip muscles, may increase our understanding of why old adults improve hip mechanical output to increase gait velocity. Second, the current thesis only studied sagittal plane biomechanics and although walking is mainly a sagittal-plane movement, it is possible that power training evoked adaptations in mediolateral direction that resulted in improved balance. Third, the generalizability of the current thesis is limited to healthy old adults with no mobility limitations. Future research is needed to ascertain if power training evokes similar adaptations in gait mechanics of elderly with low locomotor performance. Fourth, future studies should involve larger sample sizes to enhance statistical power. Lastly, the results of the present thesis are limited to lower extremity power training and is useful to examine whether adaptations in elderly’s gait mechanics are similar after different types of exercise interventions.

7.5. CONCLUSIONS AND CLINICAL IMPLICATIONS
This thesis is a first step towards understanding the biomechanical mechanisms that underlie power training-induced increases in old adults’ gait velocity. First, this thesis confirms previous reports that power training is a useful tool to evoke substantial increases in healthy old adults’ lower extremity muscle strength and power. Second, there was little to no incorporation of the newly acquired knee extensor and plantarflexor strength and power abilities into gait. These findings indicate that knee and ankle muscle power in healthy old adults is no limiting factor for walking performance. Mechanisms associated with the increases in gait velocity included higher cadence, increased hip mechanical output, and increased plantarflexor activation. Interventions that aim to improve locomotor performance in healthy old adults should include exercises designed to improve hip and ankle muscle function, and to a lesser extend knee function. It is recommended to supplement lower extremity power training with specific walking exercises so allowing the use of newly acquired abilities during gait.
REFERENCES


